A 19th Century Climate Data Catalog
White Paper
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1. Summary

The 19th century climate contains a range of extremes that includes the end of the so-called Little Ice Age and the beginning of a warming trend that is likely due, at least in part, to anthropogenically-induced increases in carbon dioxide. These and other climate events make this century important for studies of climate variability and change. Information on 19th century climate, although available, comes from a number of disparate sources. Modern instrumental climate data for the United States exist for roughly the last 105 years. Historical climate data, from sources such as the U.S. Army Medical Departments and Signal Corps and the Smithsonian Institution, extend to the late 1820s in a few areas, with greater coverage beginning after the late 1850s. High-resolution paleoclimatic data from tree rings are available for the past 300 years or more in almost all areas of the United States. These three types of climate data overlap in the 19th century, and present an opportunity to generate a spatially and temporally detailed proxy/instrumental climate data catalogue for this century. When combined with the 20th century climate record, this will result in a 200-year record of climate variability for the United States. This period of time contains climate variability and trends that include some of the coldest decades in centuries, as well as the warmest in the last 1000 years, periods of repeated drought, and anomalously wet conditions. This period also encompasses a climate impacted by human activities as well as a broad range of natural variability. As such, it represents an interval of climate variability that is extremely useful for studying regional patterns of climate, relationships between major modes of climatic variation on decadal-scale (e.g., the PDO) and interannual climate (e.g., ENSO, NAO), and natural (e.g., volcanic) and anthropogenic forcing mechanisms.

The proposed work is a synthesis activity that will bring together existing instrumental (USHCN), historical (NCDC's 19th Century Climate Project), and paleoclimatic (e.g., NGDC data from Mann et al. 2000, Cook et al. 1999, and others) datasets. It will also build upon ongoing projects to take advantage of the wealth of paleoclimatic data available for the 19th century to create upgraded reconstructions for this century. The project will address the issue of blending paleoclimatic and instrumental climate data through experimentation and collaboration with other groups, such as the Lamont-Doherty Earth Observatory and the Tree Ring Laboratory at the University of Arizona. Careful validation of all datasets will be undertaken, and we will use AMIP-type climate models to help in the validation of the reconstructed spatial patterns of climatic anomalies at seasonal time scales. The final product will be a 19th century data catalogue for the United States with paleoclimatic, historical, and instrumental data, that will include a blended climate data product if that turns out to be feasible. The dataset will be available online along with web-based tools for data search, display, simple comparisons, and access. The web page interface will also include introductory text that fully explains the data catalogue and its uses. The results of this project will lay the groundwork for a world-wide reconstruction of 19th century climate.

2. Project Goals and Components

2.1. Project goals

The long-term goal of this project is to create a North American (primarily the U.S.) reconstruction of 19^{th} century climate that incorporates paleoclimatic reconstructions, historical climate data, and instrumental climate data (climate variables to be included: mean annual and/or seasonal estimates of temperature and precipitation, drought/wetness indicators, such as the PDSI, and/or streamflow reconstructions for selected rivers and streams). The 19^{th} century is targeted for two main reasons: 1) Paleoclimatic and historical instrumental climate data are both available for this time period. There are more tree-ring chronologies available for this century than any other and many of these have not been utilized because of their relatively short length. Within the 19^{th} century, there is also a wealth of historical climate data (from documentary sources) that, if used in conjunction with other paleoclimatic data, could provide a high resolution, spatially detailed reconstruction of 19^{th} century climate. 2) Prior research indicates that 19^{th} century climate is unusual with regard to the climate of other centuries in several respects. The so-called Little Ice Age (LIA) ends in the 19^{th} century with several decades of temperatures in the early part of the century that are among the coldest in the last millennia (Mann et al. 1999). Also during this time, and likely related to the cold temperatures, there is evidence for extremes in solar variability and several very large volcanic events the magnitude of which have not been seen in the 20^{th} century (Crowley 2000). The 19^{th} century also contains a sequence of severe droughts during the 1820s, 1840s, 1860s, and 1890s over parts of the Great Plains (Woodhouse and Overpeck 1998), unlike the temporal pattern of drought in either the 20^{th} or 18^{th} centuries. Clearly the 19^{th} century is a century of climate extremes not well represented in the 20^{th} century climate record. The availability of paleoclimatic (mostly from tree rings), documentary (from numerous archival sources), and instrumental data (available at NCDC and other locations) presents us with an excellent opportunity to develop a detailed climate history of the 19^{th} century that is compatible with and comparable in quality with the modern 20^{th} century instrumental record. Such a climate history will provide a 200-year high resolution record of climate for much of North America that not only includes a span of time for which the impacts of human activities on climate have become evident, but also a range of natural variability not available in the more recent record if taken alone. In addition, discrepancies between otherwise well-matching results from energy balance models and proxy records occur at the end of the 19^{th} century (Mann et al. 2001) which may be resolved with the proposed climate dataset.

2.2. Project components

Generating a high quality spatially detailed climate reconstruction for North America (primarily the U.S.) is a large task that is best broken down into a series of components. These are as follows:

1. To blend or not to blend. One of the first issues that will be encountered will be the feasibility of blending instrumental and/or historical climate data with paleoclimatic data. Historical instrumental data records have been successfully blended (Peterson et al. 1998), but the blending of these records with non-instrumental historical and/or paleoclimatic data is more complex and more controversial. Differences in the spectral properties inherent in proxy data presents one type of problem. Other problems are related to evaluation of and confidence in the fidelity of the

final reconstructions. Discussions including both the paleoclimate and instrumental data communities, and detailed spatial and temporal tests with data will be needed to resolve this issue. We plan to collaborate extensively with a number of other climate and paleoclimate experts to try and resolve these problems. Regardless of whether the blending issue is fully resolved, part of this component will be the identification of sets of temporally overlapping records which will be useful for calibrating both paleo and historical records with each other and with instrumental records.

2. Regional reconstructions. Depending on the outcome of the blending issue, taking a regional approach to reconstructions may be a good intermediate step in order to evaluate reconstruction and blending methodologies and results for a number of different variables. A regional scale is also relevant for understanding the regional impacts (including those on human activities) of global warming. Possible reconstruction variables include seasonal and annual temperature (incorporating the ongoing work of Mann and collaborators), seasonal PDSI (a 19th century upgrade from Cook and coworkers), and selected streamflow gages, but also reconstructions of frequency and timing of daily events such as rainfall events, frost occurrence, and duration of growing season, may be possible in some regions and times. A thorough evaluation of all reconstructions is an important part of this step.

3. Development of a catalog of 19th century climate, with instrumental, historical, and paleoclimatic climate data, as well as a blended product if that turns out to be workable. The catalog would include other available and relevant climate data and reconstructions, including circulation indices, such as the SOI, Niño SST, and PDO indices, and a limited amount of SST data. This dataset would be a reference database for continued studies of climate variability and change, and applications in resource management and policy decisions. The dataset would be available online through NCDC and NOAA Paleoclimatology web pages.

4. Tools for the use of this dataset (for viewing data spatially and temporally, simple analysis and comparisons, and downloading) will be developed at the NOAA/NGDC Paleoclimatology group in collaboration with NCDC and other PI's. The tools would be available online through both NOAA-Paleo and NCDC web sites. It is envisioned that this catalog will be of use to a wide range of users, including climate scientists, resource managers, and educators. The user interface will be tailored to meet a variety of needs.

5. Currently, we have a great deal of data that could be incorporated into this project. However, in the process of creating 19th century reconstructions, we will undoubtedly discover regions that lack important historical and paleoclimatic proxy data. In addition, modeling exercises that incorporate forcing mechanisms may also point out key areas of sensitivity that would benefit from additional paleo/historical/instrumental data. Consequently, a part of this project should include evaluation of reconstructions and assessment of data needs, and the continued collection of key data, including both paleo and historical climate data records.

6. Finally, an evaluation phase of the results of the project will be performed. Independent assessments of the usefulness of the data sets, for the general scientific community, resource managers, policy makers, and other users will be undertaken, including an assessment of whether the inclusion of other climate variables would be useful and/or feasible.

7. This project will be a pilot project, the results of which (methodologies, datasets, and web tools) will form the foundation for a world-wide catalogue of 19^{th} century climate that would be part of a separately planned project.

3. Scientific Background

3.1 What we know about 19^{th} century climate

An assortment of high resolution reconstructions of North American climate that cover the 19th century currently exist, since virtually all reconstructions that have been generated include the 19^{th} century. Two sets of reconstructions have recently been produced that provide gridded temperature reconstructions for North America (Mann et al. 2000) and summer drought (Palmer Drought Severity Index) for the U.S. (Cook et al. 1999). Work is currently underway to refine both sets of gridded reconstructions. The tree-ring based PDSI reconstruction will be expanded to include Canada and Mexico and extended back before 1700, the date the original set started. The PDSI reconstructions are based on a 2 x 3 degree grid, and the multiproxy temperature reconstructions are based on a 5 x 5 degree grid, so both sets of reconstructions portray fairly broad patterns of climate.

Other tree-ring reconstructions have been produced, ranging in spatial coverage from the coterminous U.S. to specific climate stations. Except for Fritts' (1991) reconstructions of large-scale climate patterns (annual temperature, precipitation, and sea level pressure) for the U.S. from a set of western North America tree-ring chronologies, other reconstructions have focused on smaller regions. For temperature, these include gridded summer reconstructions for western North America (Briffa et al. 1992), and several more site specific reconstructions for the Sierra Nevada (Graybill and Funkhouser 1999), Cascades (Graumlich and Brubaker 1986), and northern Arizona (Salzer 2000). There are reconstructions for moisture related variables (precipitation, drought, streamflow) for many parts of the U.S. (e.g., California; Haston and Michaelsen 1997; Great Basin, Hughes and Graumlich 1996; southwestern U.S., Meko et al. 1995; Great Plains, Fritts 1983, Blasing and Duvick 1984; southeastern U.S., Stahle and Cleaveland 1992; and the eastern U.S., Stahle et al. 1988, Cook et al. 1992).

The more spatially focused reconstructions contain more region-specific climate information but lack broad coverage, while the gridded reconstructions offer a broader spatial coverage at the cost of some regional detail. This loss of regional detail is more of an issue with moisture-related variables, which have a higher degree of spatial variability. The trade-off is illustrated in a recent study that examined a mid-19th century drought in eastern Colorado that persisted in core areas for 12 years (Woodhouse et al. in review). The gridded PDSI reconstructions show widespread drought during some of the 12 years, but lack the detail to show the persistence of drought in this relatively small region. Much attention has been focused on large-scale droughts, but depending on timing and location, small droughts can have devastating and far-reaching impacts as well. This Colorado drought, though relatively small in scale, occurred in an area that is now a major economic and population center which would be devastated by a 12-year drought were it to occur today. Regional details in reconstructions are also needed to better investigate regional response to forcings such as ENSO and volcanic events and to reconstruct synoptic patterns.

In spite of these drawbacks, this collection of studies indicates some notable characteristics of 19th century climate that seem unusual enough to merit a more complete study. Fritts (1991), in his century-by-century assessment of climate, found relatively warm, dry conditions in the first two decades of the century followed in the 1830s by some of the coldest and wettest 10-year periods in the reconstruction period (1602 to 1963). These conditions prevailed in both western and eastern U.S. with temperatures especially cold in the eastern U.S. The results of Briffa et al. (1992) for summer temperature reconstructions differ somewhat but also indicate 10-year temperature averages in the early decades of the 19th century (1810s and 1830s) that rank among the top five coldest between 1600-1982 in the western U.S. These cold decades have not been closely studied, but they occurred at the end of the Little Ice Age and coincided with several major low-latitude volcanic eruptions (in 1815, 1822 and 1835) and an interval of anomalously low solar activity known as the Dalton minimum (1790-1820) (Fritts 1991, Lean et al. 1995), so there are suggestions of causal mechanisms.

In contrast, later decades of the 19th century were relatively warm and extremely dry. Fritts (1991) and Briffa et al. (1992) find 10-year periods in the 1850s and 1860s to be among the warmest in the last four centuries across the U.S, but especially in the southwestern and central U.S. Fritts reports the two ten-year periods beginning in 1842 and 1863 as the lowest and second lowest ranking in annual precipitation for the U.S. for the entire reconstruction period, 1602-1963. A review of all available drought or precipitation proxy records or reconstructions from tree rings for the central U.S. reveals a sequence of droughts in 19th century that each equal or exceed in severity the most severe droughts of the 20th century (Woodhouse and Overpeck 1998). Stockton and Meko (1983) found periods of drought in regions flanking the Great Plain occurring in the early 1820s, early 1860s, and 1890s. In the Texas-Oklahoma-Arkansas region, a 231-year reconstruction indicated that the 1950s drought was only exceeded by the 1860s drought (Blasing et al. 1988). Stockton and Meko (1975) found the driest three-year period after 1934-36 to be 1845-47, and the third driest, 1863-65 in terms of total area experiencing drought in their reconstruction of western U.S. PDSI back to 1700.

When taken together, these studies suggest a century of extremes and high variability in both temperature and precipitation unlike the prior and following centuries. Research on forcing mechanisms suggests some possible causal mechanisms (Mann et al. 2000, Crowley 2000), but the role of these forcings is far from clear. Other possible causal factors include the coincidence of certain phases of ocean/atmosphere circulation patterns and their teleconnections to regional climate. Cole et al. (in press) suggest that a strong La Niña, enhanced by a coinciding strongly persistent negative phase of the Pacific Decadal Oscillation (PDO) may have been responsible for the severe drought conditions across the western U.S. between 1855 and 1865. Other research has suggested that the Atlantic Multidecadal Oscillation (AMO) warm phase, which occurred during 1860-1880 and about 1940-1950, coincides with decreased summer precipitation over large area of the U.S., especially the Mississippi River basin and west of the Continental Divide (Enfield et al. 2001). In addition, during the warm phase of the AMO, ENSO impacts on the Mississippi River Basin, appear to be more strongly negative (i.e., dry winters during El Niño episodes).

Along with these paleoclimatic reconstructions, there exist considerable historical instrumental records for the 19th century in the U.S. (Bradley 1976). At least from about 1870, the coverage is sufficient to develop adequate statewide temperature estimates on monthly timescales, and probably the same is true for precipitation, although rigorous tests have not been performed to know for certain. Historical instrumental records of temperature and precipitation are available in quantities useful for direct comparison with paleorecords, back to about 1850 in the western half of the U.S., and back to about 1820 in much of the eastern U.S. An attempt to synthesize these data and test the ability to merge them with paleorecords for the whole of the 1800s has not yet been undertaken.

3.2 Why focus on 19th century climate?

Additional information on both temporal and spatial climate variability is available from 19th century paleo, historical, and instrumental climate records. It is fortuitous that the 19th century seems to exhibit a wider range of climate variability than other centuries in the past 500-1000 years, as well as being the most high-resolution proxy data-rich of all centuries. A detailed reconstruction for the entire U.S. will provide a longer, more complete record of regional climate variability, the character (spatial and temporal) of extreme periods of climate, and the spatial distribution of these regional patterns of climate across the continent. A reconstruction of 19th century climate, used with the 20th century climate record, will be invaluable for assessing 20th century climate variability, trends, and extremes within the context of 200 years. A 200-year record will make it possible to investigate the regional impacts of decadal-scale ocean/atmospheric circulation features. It will also provide a baseline dataset for modeling exercises and a more rigorous test of variability based on extended GCM climate simulations.

A focus on the 19th century provides a potential opportunity to increase our understanding of both the impacts of land use on climate and climate's impact on land use and human activities. The 19th century was a time of environmental and cultural change, especially in the central and western U.S. Convergence of several factors placed stresses on the landscape; Native American population displacement into the Great Plains, the expansion of Euro-Americans with their animals into and across the central and western U.S., and, to some extent, the restriction of bison into a region much smaller than their natural range (West 1995). These factors, likely in combination with drought, resulted in a deterioration of short-grass rangelands and a decimation of riparian woodlands across the central and western Great Plains. In the 20th century, a different set of human activities, including large-scale agriculture, irrigation, and fire suppression, have had other consequences for the environment, and likely for regional climate as well. A detailed climate history for the U.S. will provide a basis for investigating land use/climate relationship in regions such as the Great Plains. Understanding of environmental change, past and present, is one of the most important challenges relating to future global change. The IGBP Past Global Changes (PAGES 2000) program recently emphasized the importance of this challenge, defining a research theme called Past Ecosystem Processes and Human-Environmental Interactions.

An additional reason to focus on 19th century climate relates to a perception of its relative "recent-ness." This perception is a consideration in the application of climate reconstructions to resource planning and management. A1though western water managers may be impressed by reports of a multidecadal drought in the 16th century, this event is not likely to be a consideration in water resource planning. However, a decade-long drought in the Colorado Front Range in the 1840s and 1850s appears to be worthy of notice among Front Range water managers. Events that occurred 150 years ago are not in the distant past, and are perceived as more likely to occur in the future. This perception works to encourage the incorporation of the reconstructed climate record into resource management plans, especially if the reconstructions are of high spatial and temporal resolution. This results in more potential uses for a dataset of 19th century climate and opportunities for future resource planning that considers a broader (and more probable?) range of climate variability than afforded by the 20th century record.

3.3 Basis for undertaking this project now

There are several key reasons to develop a 19th century catalog of key climate variables now:

– Significant amounts of both climate reconstructions from proxy records and digitized historical instrumental climate data, are either currently available, or will soon become available for this data catalogue. The next step beyond compiling separate datasets of paleo, historical and instrumental data, which is what has been done up to this point on a national scale, is to assimilate these datasets into one. Accomplishing this task will then permit us to undertake a possible merging of paleo and instrumental datasets that would enable us to provide spatial data coverage that is commensurate with that in the earlier part of the 20th century.

– Generating such a dataset now is crucial as global change studies shift in focus from global to more regional scales. Questions are now being asked about the impact of global warming on regional climate. Extended regionally detailed climate reconstructions will be vital for determining the regional impacts of large-scale climate changes.

– Resource managers are starting to see that the paleoclimatic record may contain relevant and useful information for resource management. Managers are now beginning to consider paleoclimatic records as a possible tool for resource management and planning. The 19th century climate database, along with visualization and access tools, would facilitate the use of these data by resource managers.

4. Linkages

The proposed project is a synthesis activity that will build on other activities funded through NOAA that are focused in regional to hemispheric-scale climate reconstructions for periods from the 16th through 19th centuries. One such project, "Multiproxy Climate Reconstructions: Extensions in Space and Time, and Model/Data Intercomparison" (Mann et al. 2000) has developed a set of gridded annual and seasonal temperature reconstructions for the 16th through 19th century on a global scale. Other NOAA-funded work, the PDSI reconstructions from Cook et al. 1999, will be upgraded so that they are based on all available tree-ring chronologies that start in 1800 or before. This will increase the density of chronologies used for the reconstruction, and improve the spatial resolution. The project will also take advantage of the work in Cook et al.'s, NFS/NOAA-funded "Collaborative Research: Reconstructions of Drought and Streamflow over the Coterminous United States from Tree Rings with extensions into Mexico and Canada. One of the products of this study will be the reconstruction of several networks of streamflow for selected watersheds. The historical climate part of the database will largely based on data from the ongoing NCDC 19th century climate project, and instrumental climate data will come from the NCDC USHCN database.

This project will also contribute to several NOAA and NSF programs. The work will make an important contribution to the evolving NOAA Climate Services program by providing data on 19th and 20th century climate in a form that is easy to use and understandable to a wide range of users. The new climate data products will be available and potentially useful to resource managers and policy makers. One way we will make contact with potential users is through the activities of the NOAA/OGP-funded Water Assessment for the Interior West (or Western Water Assessment, WWA, WWA for short). The WWA is a Regional Integrated Sciences and Assessments (RISA) program sponsored by NOAA, which has the goal of determining how to make climate information relevant and useful to regional planners and decision makers. This project will also contribute to a critical part of Climate Services activities, the observing system, which includes the collection and archival of pre-instrumental records from paleoclimatic data.

The goals of this project are also relevant to NOAA's Climate Change Data and Detection Program element which supports the development, analysis, and archival of data to enhance our understanding of climate variability and change on time scales from days to centuries. This project will yield a high-quality climate dataset that will be useful for a variety of science needs, especially for interannual to decadal climate analyses. We will particularly address issues of calibration, validation, and the blending of three different types of climate data: proxy, historical, and instrumental,

The proposed work is closely aligned with the goals and foci of the NSF Earth System History (ESH) program. The main goal of ESH is to increase our knowledge of the natural variability inherent in the Earth's climate system and this work will make an important contribution to this goal. More specifically, this work will synthesize and integrate data into a database to be used to investigate Holocene climate variability and forcing mechanisms. The spatially detailed climate reconstructions for the U.S. will reveal regional patterns of past climate and shed light on the changes in these spatial patterns over the 19th and 20th centuries. The database will provide a test for model evaluation in terms of simulating the range of variability in 19th and 20th centuries.

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